

CHAPTER 2

GENERAL SYSTEM TESTING REQUIREMENTS

2-1. Introduction

The purpose of electrical testing on systems and their components is two-fold. The first is to check the installation of the equipment and perform component and systems tests to ensure that, when energized, the system will function properly. The second is to develop a set of baseline test results for comparison in future testing to identify equipment deterioration. Commissioning tests are usually performed by independent contractors, the installation contractor, or the manufacturer. Each commissioning test should be witnessed by a person not associated professionally with the person performing the test. The individuals who perform the acceptance tests should be certified and/or licensed for the equipment under test. The system should be initially checked for damage, deterioration, and component failures using specific component checks, inspections, and tests defined by the equipment manufacturer. Then the interconnection of the system components should be checked, using de-energized and energized methods, to verify the proper interconnection and operation of the components, including on/off control, system process interlocks, and protective relaying functions. Once the above tests are complete, the system can be energized and operational tests and measurements should be performed. All steps and results of the testing should be carefully documented for review and for use in the future for comparison with the results of future tests. Many of the same component tests initially run will be performed at regular intervals as part of a maintenance program. The new results will be compared to the initial results, where variations may be indicative of problems like deterioration of insulation or dirty equipment. The steps involved are to review the system and equipment, develop a general system and specific equipment test plan, provide inspection and checks, perform component testing, verify and check the continuity of wiring, check control functions, calibrate instruments and relays, energize portions of the circuits and check for proper operation in a specific order, and, once complete, perform specific checks and control tests on the complete system during initial period of operation.

2-2. General test plan

There are management, economic, and technical requirements associated with every test plan. The development and use of a comprehensive test plan is like an insurance policy. While it has specific costs, it does not usually show any direct paybacks as the systems will usually startup without significant problems such as equipment failure or lost time. The cost of the tests will rise with the complexity of the test program. Many inspections and tests are redundant, but are used as checks and balances before system energization to ensure successful startup and operation. Many times, if the equipment is in the same operating condition as when it left the factory and the system design and installation are adequate, the system startup and testing will find no problems and the de-energized checks and energized testing may seem like a waste of time and money. There are occasions when a test will show bad insulation like a faulted transformer winding or a missing interlock in a control scheme that would have resulted in catastrophic failure if the system had been energized. The complexity of the system and equipment, experience of the designers/installers/operators, the possible results of a failure, and the costs of the testing are all considered when determining the amount of testing required. The component and system inspections and checks are the key to the success of the program. Sufficient time should be allocated to define the inspections required, perform the check, and document the results. A review of the system drawings will show major pieces of equipment. Specific procedures should be developed for each commissioning test referencing the equipment to be used, systems operation documents (SODs), systems

operation and maintenance manuals (SOMMs), drawings to be followed, and step by step procedures with readings to be recorded and forms for the results. Once the equipment is identified, the manufacturer's manuals should be used to identify the required receipt inspections, handling and installation procedures, energized and de-energized component tests, drawing and wiring verification, minimum report requirements for on-going maintenance and testing baseline, and requirements for repair and retesting if certain checks and tests produce unsatisfactory results. To perform the testing, a definite plan listing all required tests in order of performance and giving a schedule for each test should be developed. The work items and schedule will depend on many items including the importance and cost of the equipment, consequences of failure, age of equipment, past and future frequency of service, hours of operation, future maintenance availability, environmental conditions, and safety requirements. (For remote unattended systems, additional items will be required in the initial test plan, to help assure all possible operating sequences, malfunctions, and corrections have been verified. The plan should be revised as the inspection and testing proceeds depending on the acceptability of the results.) Certain failures may require retesting of component and system operation. When wiring problems are found and repaired, all affected wiring terminations should be re-verified for their proper connections. The success of a test program and its use to support an on-going maintenance program also greatly depends on the attention given to development and review of the test records and reports by the testing and operations personnel and system management. To have an effective program it is imperative that test data be complete, organized, and readily available. Forms should be developed with the test procedures which list the required test procedure, test sequence, test instrument, test data and, most importantly, acceptable test values for each result. (Examples of test forms are found in each applicable chapter. These forms should only be used as samples.) A remarks area should be included to list any pass or fail, comments, recommendations for repair and retest, additional follow-up testing required during the next steps of the system operation, and helpful information for future testing. Note that the data collected and recorded will be used over the years to analyze trends for equipment deterioration or help determine causes for system malfunctions, so if the records are not complete and correct a large part of the usefulness of a good test program is lost. The technical requirements for a test program can be stated as follows.

a. Survey of system equipment. An accurate and complete description of a power system and its equipment is required to develop a test program. This will include written system description, one-line diagrams, short circuit and coordination studies, three line diagrams, control logic diagrams, schematic logic diagrams, cable block and interconnecting diagrams, equipment physical and wiring drawings, equipment manuals, and auxiliary system manuals and drawings for support systems such as lighting, fire protection, backup power, building and building services, etc.. These documents serve to depict the design and operation of the system for use during installation, testing, startup, operation, and maintenance. Various standards groups such as the Institute of Electrical and Electronics Engineers (IEEE) and National Electrical Manufacturers Association (NEMA) have developed standards for these materials. Typical drawings and their definitions are as follows:

(1) *One-line (single-line) diagram.* Shows, by means of single lines and graphic symbols, the flow of electrical power or the course of electrical circuit symbols, and how they are connected. In this diagram, physical relationships are usually disregarded.

(2) *Block diagram.* Shows a group of interconnected blocks, each of which represent a device or subsystem.

(3) *Schematic (elementary) diagram.* Shows all circuits and device elements of the equipment. This diagram emphasizes the device elements and their functions, and it is always drawn with all devices shown in deenergized mode.

(4) *Control sequence (truth-table) diagram.* Shows a description of the contact positions, connections, that are made for each position of control action or device.

(5) *Wiring diagram (connection diagram).* Locates and identifies electrical devices, terminals, and interconnecting wires in an assembly. This diagram may show interconnecting wiring by lines or terminal designations.

(6) *Interconnection diagram.* Shows only the external connection between controllers and associated equipment or between various housing units of an assembly of switchgear apparatus.

(7) *Circuit layout and routing diagram.* Shows the physical layout of the facility and equipment and how the circuit to the various equipment is run.

(8) *Short-circuit coordination study.* Electrical power system data, diagrams, and drawings are needed during maintenance and testing of electrical equipment. This may involve information and data relating to protective devices and relays. Such data are usually found in a short-circuit coordination study and usually encompass all the short-circuit values available in the power system, relays, and trip device settings. Normally, this study is performed during the construction phase of the facility. It would be much more desirable to perform this engineering study as part of the initial facility design, and then validate it during the construction phase to assure that equipment and values specified have been met. When accepting the facility, this study data should be used as a benchmark, and any changes that may have been made during construction in the system should be incorporated to update the study for future references.

b. Listing of critical system equipment. The major equipment of a system is vital to its operation and failure of this equipment could be a threat to personnel and system operation, i.e., potential single point failures. From a review of the system documentation, especially the single line diagram, a list of critical equipment and the order in which the items should be inspected, tested, and energized should be developed. From this list, the plan and schedule for the test program can be developed. Normally the listing in order of criticality of the equipment is from the normal power source into the system with onsite sources failing after the main power source and distribution equipment. The listing may be difficult to prepare as it will vary for each system, and therefore a team from system engineering, operations, and maintenance may be required. This will also serve to provide the operations and maintenance personnel an opportunity to review the system during the early stages of a project, which helps them in the performance of their work.

c. Steps for the test program. A test program will commence after completion of installation and will usually include field inspection and installation checks, de-energized component testing, verify instrument and relay operation and calibration, visual check of all wiring, continuity checking of control circuits, energized functional testing of control circuits, megger testing of power circuits, test of power circuits phasing, energizing of equipment, and service testing. If problems are found during the testing; an analysis should be performed, and a repair and retest should be performed that is approved by the commissioning authority, manufacturer, engineer, and system operator. Many of these initial tests will be repeated periodically as part of the system maintenance program depending on the load conditions, duty cycle, environmental conditions, and the critical nature of the equipment. Because of this, the completeness and clarity of the test reports is important as they supply baseline data for comparison with the results of the maintenance tests.

d. General definition of test steps. Prior to testing, overall completion of installation should be verified including setting, wiring, grounding of the equipment, and conditioning of the overall area, i.e., clean complete site to work in. This is considered a pretest. Note: all of the items below should be

performed in strict accordance with the drawings, systems operations documents, systems operation and maintenance manuals (provided by contractor), and the engineer's and manufacturer's instructions for each piece of equipment. The manufacturer typically provides the instructions in the form of diagrams indicating how to connect the test instruments as well as charts indicating acceptable and unacceptable values. The engineer's instructions will be found in the system specifications and drawings, and the manufacturer's instructions are found in the equipment manuals and drawings. IEEE, NEMA, National Fire Protection Association (NFPA), and other standards also include acceptable procedures for the performance of the tests. As the acceptance tests and energization is performed; failures and repairs, availability of equipment and personnel, schedules, weather, and other items may cause the delay or non-performance of a test. In any of these cases, the missing, failed, newly required, or postponed test should be noted in the test documentation along with the reason for missing the test and the technical consequences. An evaluation should be made as to whether the system can be energized without this test noting the possible effect on safety, personnel, and equipment operation; and noting when or even if the test should be performed in the future. If the test yet to be performed or needs to be performed to prove the adequacy of a repair, the test should be scheduled with the system operations personnel as part of an on-going maintenance program.

(1) *Field inspection and installation checks.* Include inspection of impact recorders, verification of removal of shipping braces, inspection of installation against drawings and nameplates, inspecting of components for damage and cleanliness, inspection of insulators for cracking, inspection of anchorage and grounding, sizing check of fuses and breakers, alignment and adjustment checks, mechanical operation and interlock checks, lubrication application, verification of insulating liquid or gas level or pressure, and verification that local safety equipment is in place.

(2) *De-energized component testing.* Include pressure and level checks, megger and insulation resistance testing of equipment and connections including grounds, turns ratio measurements, polarity tests, insulating liquid dielectric and moisture testing, power factor or dissipation factor tests, overpotential tests, contact resistance measurements, operation time travel analysis, battery and cell voltage measurements, charger/UPS (uninterruptible power supply)/generator current and voltage measurements, and equipment/systems impedance or resistance tests.

(3) *Verification of instrument and relay operation and calibration.* Include verification of auxiliary device operation, calibration of instruments and relays, functional testing of individual instruments/gauges/alarms/relays/limit switches/etc.

(4) *Visual check of all wiring.* Include visual inspection of all wiring against the schematic and wiring, both internal and external, diagrams.

(5) *Continuity checking of control circuits.* Include continuity and voltage testing of all control circuits against schematic diagrams.

(6) *Energized functional testing of control circuits.* Include energizing of control circuits and checking all remote and local close/trip operations, protective relay operations, safety and interlock operations, and all process and communication operations.

(7) *Megger testing of power circuits.* Include megger testing of power, current transformer, and potential transformer buses and cables after connection.

(8) *Phase out testing of power circuits.* Include primary and/or secondary injection testing for circuit impedance and polarity checks.

(9) *Energizing of equipment.* Include energizing of equipment in specific order after all above testing is complete and evaluated.

(10) *Service testing.* Include measurement of value and relationship of power, potential, and current on sources, buses, feeders, and neutrals in the power system.

(11) *Post acceptance tests.* Include on-going maintenance and operation tests, corrective action tests, and deferred testing.

e. Reports, forms, and records. Accurate and complete reports, forms, and records should be developed and kept updated after the testing for the equipment and the system for initial evaluation of the results before energization and on-going evaluation by operations and maintenance. Analysis of the data and results should provide a decision to startup and a guide for future maintenance requirements and its cost. Figures should be kept for the time, cost, and equipment used for each test for input to the development of the maintenance program. Care should be taken to ensure that extraneous information does not become part of the record, because record keeping might hamper future use. Test reports giving test description and basic procedure, components, drawing and other document references, test circuit diagrams, test equipment model and age and calibration date, special tools required, test forms with results filled in, time to run the test, acceptance criteria, failure or unusual event information, recommended repair, and when the test should be performed again for equipment maintenance should be developed for the tests. Summary logs developed from the information can be used for developing and scheduling an on-going maintenance program. Forms should be used to document the results of testing procedures. They should be detailed and direct, but simple and durable enough to be used in the field. The forms should be used as input to the development of the test reports. A well designed form will contain checklist information for inspections, test procedures, safety and special precautions, required equipment and tools, reference drawings and manuals, acceptance criteria, estimated time to perform the test, and remarks/event recording area. Sample forms for basic equipment and tests are attached.

f. Special precautions and safety. Many tests on electrical equipment involve the use of high voltages and currents that are dangerous, both from the standpoint of being life hazards to personnel and because they are capable of damaging or destroying the equipment under test. Adequate safety rules should be instituted and practiced to prevent injury to personnel, both personnel who are performing the tests and others who might be exposed to the hazard. Also, the test procedures used should be designed to ensure that no intentional damage to equipment will result from the testing process. It should be recognized, as the name implies, that over-potential or high-potential testing is intended to stress the insulation structure above that of normal system voltage. The purpose of the test is to establish the integrity of the insulation to withstand voltage transients associated with switching and lightning surges and hence reduce the probability of in-service equipment failures. Direct voltage over-potential testing is generally considered a controlled, nondestructive test in that an experienced operator, utilizing a suitable test set, can often detect marginal insulation from the behavior of measured current. It is therefore possible, in many cases to detect questionable insulation and plan for replacement without actually breaking it down under test. Unfortunately, some insulations might break down with no warning. Plans for coping with this possibility should be included in the test schedule. Low-voltage insulation testing can generally be done at the beginning of the planned maintenance shutdown. In the event of an insulation failure under test, maximum time would be available for repair prior to the scheduled system start-up. Equipment found in wet or dirty condition should be cleaned and dried before high-potential testing is done or a breakdown can damage the equipment. Low-voltage circuit breakers, which require very high interrupting ratings, are available with integral current-limiting fuses. Although the fuse size is selected to override without damage to the time-current operating characteristics of the series trip device, it is desirable to bypass or remove the fuse prior to applying simulated overload and fault current. If a testing program is to provide meaningful information relative to the condition of the equipment under test, then the person evaluating

the test data must be ensured that the test was conducted in a proper manner and that all of the conditions that could affect the evaluation of the tests were considered and any pertinent factors reported. The test operator, therefore, must be thoroughly familiar with the test equipment used in the type of test to be performed and also sufficiently experienced to be able to detect any equipment abnormalities or questionable data during the performance of the tests.

g. Test equipment. It is important that in any test program the proper equipment is used. The equipment should be calibrated, in good condition, and used by qualified operators. Any test equipment used for calibration shall have twice the accuracy of the equipment to be tested. Care should be taken to use a quality or regulated power source for the equipment as voltage, frequency, and waveform variation can produce invalid results. All equipment should be operated in accordance with its instruction manual.

h. Sample Commissioning (Cx) Plan: The primary intent of this technical manual is to propose different procedures that should be considered when commissioning a new electrical system and/or component. The figures, forms, and tests in this manual are only examples of the concepts that should be implemented when developing a commissioning plan. The following paragraphs discuss an example of commissioning program planning stages that can be used to commission a new system as shown in figure 2.1 (Commissioning Plan Example). The time period in which a commissioning process begins determines what steps in the planning stages are considered:

(1) Initial commissioning (kick-off) meeting. The first commissioning meeting may start as early as before a contract is awarded or as late as after the system has been installed (before it is turned over to the customer). The participants in the meeting should include customer, government contractor personnel, participating engineers, commissioning personnel (may be an independent commissioning contractor or government engineer), general contractor, and electrical and mechanical sub-contractors. Topics of meeting should include areas of responsibility, expectations, overall presentation of system, methodology, potential problem areas, etc. The participants should be all considered "part of a team".

(2) Review initial statement of work (SOW). All participants should review the SOW that describes the requirements of the commissioning process. The customer (or designated authority) should have the ultimate control where decisions are required.

(3) Review drawing submittals. After the systems are installed, drawings should be submitted for review and comment. Sometimes the review may be before systems are installed. Care must be taken to verify that the drawings submitted reflect the actual installed system.

(4) Approval meeting. After the SOW and drawing submittals have been submitted, reviewed, comments made, and comments incorporated, approval of documents should be provided.

(5) Systems operation document (SOD)/systems operation and maintenance manual (SOMM) document. Prime contractor should provide a SOD or SOMM. These documents are required in order to develop specific commissioning tests.

(6) Submit functional performance tests (FPTs). System/component tests or FPTs should be developed from submitted drawings, SODs and SOMMs. The tests should include large

component testing (i.e. transformers, cable, generators, UPS), and how components operate as part of the total system. The test should be developed by the commissioning authority. The commissioning authority should not be the installation contractor (or sub-contractor).

(7) *Quality assurance.* As the equipment/components/systems are installed quality assurance procedures should be administered to verify components are installed in accordance with minimum manufacturers recommendations, safety codes, and acceptable installation practices. Quality assurance discrepancies should be identified and added to a "commissioning action list" that must be rectified as part of the commissioning program. These items would usually be discussed during commissioning meetings. Discrepancies are usually identified initially by visual inspection.

(8) *Review FPTs.* The tests should be reviewed by the customer, electrical contractors, quality assurance personnel, maintenance personnel, etc (the commissioning team). Areas of concern should be 1) are all functions of the system being tested, 2) are all major components included, 3) do the tests reflect the system operating documents, 4) do the tests make sense, etc.

(9) *Make changes to FPTs.* This is where corrections, questions answered, and additions made will be implemented. This will be done by the commissioning authority.

(10) *FPT approval.* After the changes are made to the FPTs they will again be submitted to the commissioning team. When it is acceptable the customer or his/her designated approval authority should approve the FPTs. It should be noted that even though the FPT is approved, problems that arise during the test (or areas not covered) should be addressed.

(11) *Systems operate.* The FPTs can be implemented as various systems become operative (i.e. test the generator system) or when the entire system is installed. However the final "pull the plug" test will be performed after all systems are completely installed. If the FPTs are implemented by the electrical contractor (or sub-contractor) then a witness should initial each step of the test. The witness should not be employed directly or indirectly by the electrical contractor.

(12) *Customer receives system.* After all tests are completed (including the "pull the plug" test) the system should be turned over to the customer.

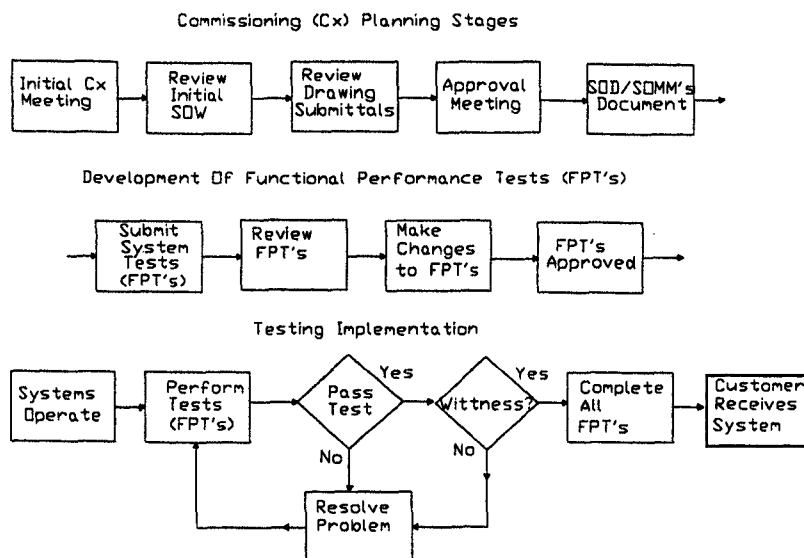


Figure 2-1. Sample of a commissioning plan

2-3. Types of testing methods

Types of testing methods include the four categories of tests as well as the tests themselves.

a. Categories of tests. There are four categories of tests for electrical equipment; factory, acceptance, routine maintenance, and special maintenance. Factory tests are performed at the factory to prove the equipment was manufactured properly and meets specific design parameters. Commissioning tests, the main subject of this document, are also proof tests performed on new equipment and systems usually after installation and before energization. They are run to determine whether the equipment is in compliance with specifications, to establish benchmarks for future tests, to determine the equipment was installed correctly and without damage, and to verify whether the equipment meets its intended design operation and limits. Routine and special maintenance tests are run after the equipment has been in service for a certain amount of time to determine the degree of deterioration of certain equipment physical parameters as operating time increases. Routine tests are performed on a periodic basis and special tests are performed on defective equipment to help determine the cause of a failure and/or the extent of the damage. The same type of tests and measurements are performed for all of the categories using different voltage values. The acceptance tests are usually run at 80% and the maintenance tests are usually run at 60% of the factory test voltage values to help indicate deterioration without being destructive.

b. Types of testing methods. The testing of electrical power system equipment involves checking the insulation adequacy, electrical properties, protection and control, operation, and other items as they relate to the overall system. Some of these checks are accomplished using de-energized component tests, instrumentation and relay operation and calibration tests, energized functional testing of control circuits, megger testing of power circuits, phase out testing of power circuits, and service testing.

2-4. Insulation testing

Insulation can either be solid, liquid, or gaseous dielectric materials that prevent the flow of electricity between points of different potential. Insulation testing is performed to determine the integrity of the

insulation. This usually consists of applying a high potential voltage to the item and measuring the leakage current that may flow to ground. Excessive leakage current is an indication of dielectric breakdown and/or impending failure. Insulation may weaken over time at a rate tightly related to the operating time and temperature of operation. Therefore, these tests are run periodically to track the insulation deterioration. Insulation testing, the most common electrical testing performed, can be performed by applying a direct current (dc) or alternating current (ac) voltage. The type and value of the voltage determines whether the test is considered non-destructive or destructive. The higher the voltage, the more destructive the test. Usually destructive tests are only run one time in the factory to verify the initial strength of the insulation, and non-destructive tests are run as acceptance and maintenance tests to measure deterioration from the original value. Both the dc and ac tests are "go no-go" tests. In addition, the dc test can indicate the amount of deterioration and forecast the remaining time for safe operation by comparing the leakage current and test voltage to values from previous tests.

a. Advantage of direct-current testing. Direct-current test is preferred on equipment whose charging capacitance is very high, such as cables. Direct-current voltage stress is considered much less damaging to insulation than ac voltages. The time of voltage application is not as critical with dc voltage as with ac voltage. The test can be stopped before equipment failure. Measurements can be taken concurrently. It is not necessary to make a separate insulation resistance test prior to making a dc over potential test.

b. Disadvantage of direct-current testing. The stress distribution for transformers, motors, and generator winding is different for dc voltage than for ac voltage. The residual charge after a dc voltage test must be carefully discharged. The time required to conduct a dc high-potential test is longer than for an ac high-potential test.

c. Direct-current (dc) testing. When a dc potential is applied across an insulation, the resultant current flow is composed of several components as follows:

(1) Capacitance-charging current. Capacitance-charging current is the current resulting from charge absorbed by the capacitor formed by the capacitance of the bushing. This current is a function of time which also depends on applied dc voltage, insulation resistance and the time constant of the circuit.

(2) Dielectric-absorption current. Dielectric-absorption current is the current that is absorbed and trapped in the dielectric during the charging of the piece of equipment and released after the equipment is discharged. This current can be calculated from test voltage, capacitance, and time. In air-cooled and hydrogen-cooled ac rotating machines, dielectric absorption varies with temperature.

(3) Surface leakage current. The passage of current over the surface of an insulation rather than through its volume is surface leakage current. In measuring insulation resistance of armature and field windings in rotating machines (rated 1 hp, 750 W or greater), a high surface leakage current is usually caused by moisture or another type of partly conductive contamination present in the rotating machine.

(4) Partial discharge (corona current). This is a type of localized discharge resulting from transient gaseous ionization in an insulation system when the voltage stress exceeds a critical value. Partial discharge is not desirable and should be eliminated. It is caused by overstressing of air at sharp corners of the conductor due to high test voltage. In shielded power cable systems (rated > 5 kV), humidity or wind can increase the corona current.

(5) Volumetric leakage current. The current that flows through the volume insulation itself is volumetric leakage current. It is the current that is of primary interest in the evaluation of the condition of the insulation. In shielded power cable systems (rated > 5 kV), humidity, condensation, and precipitation on the surface of a termination can increase surface leakage current and volumetric leakage current. Surface leakage current and

volumetric current added together is the quotient of the applied dc voltage and insulation resistance. In large ac rotating machines rated 10,000 kVA or greater and rated 6000 V or higher, moisture, on the end windings, increases surface leakage current and volumetric leakage current especially when dirt is also on the winding. Since the insulation may weaken over time, age may cause an increase in the various currents during testing.

d. Insulation-resistance (megger) testing. For equipment containing electronic components, megger testing must not be performed. However, this equipment should be tested according to manufacturer specifications. In an insulation-resistance test, an applied voltage, from 600 to 5000 volts, supplied from a source of constant potential, is applied across the insulation. The usual potential source is a megohmmeter, also known as a megger, either hand or power operated that indicates the insulation resistance directly on a scale calibrated in megohms. A megohmmeter that is a hand cranked, a rectifier-type, or battery-operated instrument is suitable for testing equipment rated up to 600 volts. For equipment rated over 600 volts, use of a 1000-volt or 2500-volt motor-driven or rectifier-type megohmmeter is recommended for optimum test results. The quality of the insulation is evaluated based on the level of the insulation resistance. The insulation resistance of many types of insulation is variable with temperature, so the data obtained should be corrected to the standard temperature for the class of equipment under test. Published charts similar to table 2-1 are available for this purpose. The megohm value of insulation resistance obtained will be inversely proportional to the volume of insulation being tested. For example, a cable 1000-ft (304.8 m) long would be expected to have one-tenth the insulation resistance of a cable 100-ft (30.48 m) long if all other conditions were identical. The insulation-resistance test is relatively easy to perform and is a useful test used on all types and classes of electrical equipment. Its main value lies in the charting of data from periodic tests, corrected for temperature, over the life of the equipment so that deteriorative trends might be detected.

Table 2-1. Recommended minimum insulation resistance values at 40°C (all values in MΩ).

Minimum Insulation Resistance after 1 minute (MΩ)	Test specimen
kV + 1 (Example: 15 kV machine is 15 + 1 = 16 MΩ)	For most windings made before about 1970, all field windings, and others not described below
100	For most dc armature and ac windings built after about 1970 (form-wound coils)
5	For most machines with random-wound stator coils and form-wound coils rated below 1 kV

Notes: kV is the rated machine terminal to terminal voltage, in rms (root mean square) kV.

Recommended minimum insulation resistance values above, in megohms, at 40°C of the entire machine winding for overvoltage testing or operation of ac and dc machine stator windings and rotor windings.

From IEEE Std. 43-2000. Copyright © 2000 IEEE. All rights reserved.

e. Dielectric absorption testing. In a dielectric-absorption test, a voltage supplied from a source of constant potential is applied across the insulation. The test voltage used may have to be significantly higher than the insulation-resistance test in order to obtain measurable current readings. The potential source can be either a meg-ohmmeter, as described above or a high-voltage power supply with an ammeter indicating the current being drawn by the specimen under test. The voltage is applied for an extended period of time, from 5 to 15 minutes, and periodic readings are taken of the insulation resistance or leakage current. The test data is evaluated on the basis that if an insulation is in good condition, its apparent insulation resistance will increase as the test progresses. Unlike the insulation-resistance test, the dielectric-absorption test results are independent of the volume and the temperature of the insulation under test. For the dielectric absorption test, the values recorded at each one minute interval are plotted on log-log paper with coordinates for resistance versus time. The slope of the resulting curve gives a good indication of the insulation condition. A good insulation system will have a

slope that is a straight line increasing in respect to time. The characteristic slope of a poor insulation system will be a curve that flattens out with respect to time.

f. Polarization index testing. The polarization index is a specialized application of the dielectric absorption test. The index is the ratio of insulation resistance at two different times after voltage application, usually the insulation resistance at 10 minutes to the insulation resistance at 1 minute. The use of polarization-index testing is usually confined to rotating machines, cables, and transformers. A polarization index less than 1.0 indicates that the equipment needs maintenance before being placed in service. References are available for polarization indexes for various types of equipment as well as in table 2-2. Acceptance testing specifications for Electrical Power and Distribution Equipment and Systems NETA 1999 and Recommended Practice for Testing Insulation Resistance of Rotating Machinery (IEEE Std. 43-2000) are references available for polarization indexes for various types of equipment. The polarization index test lasts for 10 minutes. The insulation resistance is recorded after 1 minute, then again after 10 minutes. The polarization index is the quotient of the 10-minute and 1 minute readings as shown in the following equation:

$$PI = R_{10}/R_1 \text{ (dimensionless)}$$

Where:

PI = polarization index

R = resistance.

For polarization indexes in transformers an acceptable value would be 2 or higher, values between 2 and 1 indicate marginal condition, and values below 1 indicate poor condition. After insulation resistance readings have been made, the test voltage is returned to zero and the insulation is discharged.

g. High-potential testing. A high-potential test (hi-pot) consists of applying voltage across an insulation at or above the dc equivalent of the 60-Hz operating crest voltage. The dc equivalent of the 60-Hz operating crest voltage is calculated using the following equation:

$$V_{ac} = V_{dc} / \sqrt{2}$$

Where:

V_{dc} is the equivalent dc voltage

V_{ac} is the operating crest ac voltage

The hi-pot test can be applied either as a dielectric-absorption test or a step-voltage test. DC high potential tests are "go no-go" tests. The cable is required to withstand the specified voltage for the specified time duration. These tests will normally reveal major problems due to improper field handling, improperly installed accessories or mechanical damage. Recommended test voltages are given in standard tables for dc and ac. To perform the dc Hi-pot test the input voltage to the test set should be regulated. The current-sensing circuits in test equipment shall measure only the leakage current associated with the cable under test and shall not include internal leakage of the test equipment. Record wet-bulb and dry-bulb temperatures or relative humidity and temperature. The wet bulb temperature is defined as the temperature given by a thermometer bulb which is covered with an absorbent material (linen wet with distilled water) and exposed to the atmosphere so that evaporation will cool the water and the thermometer bulb. The dry-bulb temperature is defined as the temperature of the atmosphere given by an ordinary thermometer. Test each section of cable individually with all other conductors grounded. All shields must also be grounded. Terminations shall be adequately corona-suppressed by guard ring, field reduction sphere, or other suitable methods as necessary. Precaution should be taken to insure that the maximum test voltage does not exceed the limits for terminations specified in IEEE Standard 48 or manufacturers specifications. When applied as a dielectric-absorption test, the maximum voltage is applied gradually over a period of from 60 to 90 seconds. The maximum voltage is then held for 5 minutes with leakage-current readings being taken each

minute. In cables, high ambient temperature or humidity at the ends of improperly prepared cables can raise the dc leakage current to many times its normal value. When applied as a step-voltage test, the maximum voltage is applied in a number of equal increments, usually not less than eight, with each voltage step being held for an equal interval of time. A typical voltage versus time graph as shown in figure 2-2. The time interval between steps should be long enough to allow the leakage current to reach stability, approximately 1 or 2 minutes. A leakage-current reading is taken at the end of each interval before the voltage is raised to the next level.

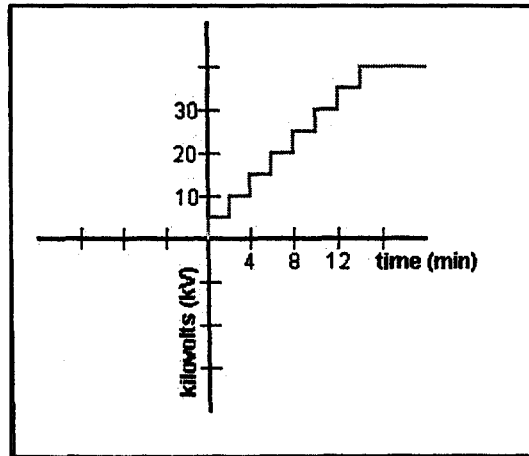


Figure 2-2. Step-voltage versus time

A plot of test voltage versus leakage current or insulation resistance is drawn as the test progresses. A nonlinear increase in leakage current can indicate imminent failure, and the test should be discontinued. See figure 2-3.

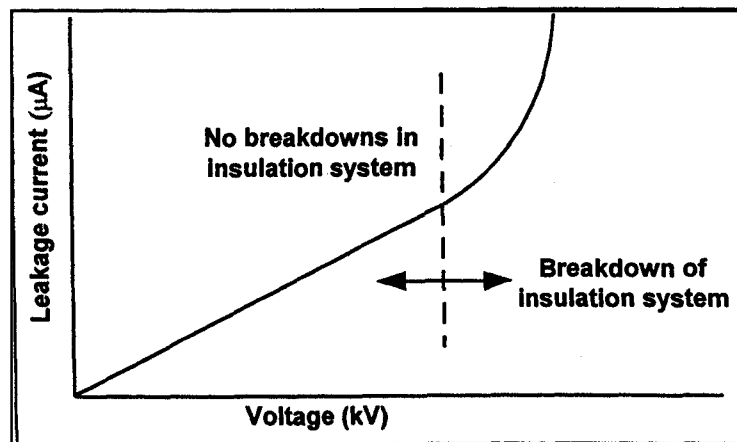


Figure 2-3. Step-voltage high-potential test current

After the maximum test voltage is reached, a dielectric absorption test can be performed at that voltage, usually for a 5-minute period.

h. AC high-potential testing. Alternating-current high-potential tests are made at voltages above the normal system voltage for a short time, such as 1 minute. The test voltages to be used vary depending on whether the device or circuit is low or high voltage, a primary or control circuit, and whether it was tested

at the factory or in the field. Manufacturers' instructions and the applicable standards should be consulted for the proper values.

i. *Insulation power-factor testing.* The power factor of an insulation is a measure of the energy component of the charging current. Power-factor testing is used to determine the power factor of an insulation system. Power-factor testing is a useful tool in evaluating the quality of insulation in power, distribution, and instrument transformers; circuit breakers; rotating machines, cables; regulators; and insulating liquids. The equipment to be tested should be isolated from the rest of the system, if practical, and all bushings or terminations should be cleaned and dried. The test should be conducted when the relative humidity is below 70 percent and when the insulation system is at a temperature above 32°F (0°C). The test equipment used should be such that the power factor or dissipation factor can be read directly or such that the charging volt-amperes and the dielectric losses can be read separately so that a ratio might be computed. The test equipment should also have sufficient electromagnetic interference cancellation devices or shielding to give meaningful test results even when used in an area of strong interference, such as an energized substation. Electromagnetic interference distorts the readings, yielding incorrect values. The desired measurements should be performed following the operating instructions supplied with the test equipment. The lead connections may have to be changed several times, depending on the complexity of the apparatus and test equipment. A meaningful evaluation will include comparison to manufacturer's results taken at the factory and/or nameplate data. On transformer tests, obtain the power factor of each winding with respect to ground and each winding with respect to each other winding. In addition, tests should be made of each bushing with a rated voltage above 600 volts, either using the power factor or capacitance tap if the bushing is so equipped or by use of a "hot-collar" test using a test electrode around the outside shell of the bushing. On higher voltage circuit breakers, the power factor of each line-side and load-side bushing assembly complete with stationary contact and interrupters, with the circuit breaker open, and each pole of the circuit breaker with the breaker closed should be obtained. On ac rotating machines, the neutral connection on the stator should be removed and a test of each winding with respect to the other two windings and ground should be obtained. For cables, the power factor of each conductor with respect to ground should be obtained and a hot-collar test should be made of each pothead or termination. Power-factor testing of insulating oil should be performed in accordance with American Society for Testing and Materials (ASTM) D 924, Standard Test Method for Dissipation Factor (or Power Factor) and Relative Permittivity (Dielectric Constant) of Electrical Insulating Liquids.

2-5. Switch/circuit breaker testing

In addition to the insulation testing mentioned above, for large switches and circuit breakers the following tests can be applied.

a. *Circuit breaker time-travel analysis.* This test, used on medium and high-voltage circuit breakers provides information as to whether the operating mechanism of the circuit breaker is operating properly. This test can be used to determine the opening and closing speeds of the breaker, the interval time for closing and tripping, and the contact bounce. The test provides information that can be used to detect problems such as weak accelerating springs, defective shock absorbers, dashpots, buffers, and closing mechanisms. The test is performed by a mechanical device that is attached to the breaker. One device, a rotating drum with a chart attached, is temporarily connected to the chassis or tank of the breaker. A movable rod with a marking device attached is installed on the lift rod portion of the breaker. As the breaker is opened or closed, the marking device indicates the amount of contact travel on the chart as the drum rotates at a known speed. With another available device, a transducer is attached to the movable rod, and the breaker operation is recorded on an oscillograph.

b. *Contact-resistance testing.* This test is used to test the quality of the contacts on switches and circuit breakers. A test set designed for this purpose is available with direct-scale calibration in microhms, capable of reading contact resistances of 10 microhms or less. An alternate method is to pass a

known level of direct current through the contact structures and to measure the dc millivolt drop across the contacts. The data obtained can then be converted to resistance by applying Ohm's Law. The alternate method requires a source of at least 100 amperes with a millivolt meter of approximately 0-20 mV range.

2-6. Transformer testing

Transformers are subject to the following tests in addition to the insulation testing mentioned above in paragraph 2-4. However, dry-type transformers would not be subject to fault-gas analysis and insulating liquid analysis due to the fact that these types of transformers usually feature a gaseous or dry compound insulating medium. Cast coil transformers, which are defined as a transformer with high-voltage coils cast in an epoxy resin, would also not be subject to fault-gas analysis and insulating liquid analysis due to the fact that the core and coils of these types of transformers are not immersed in an insulating liquid. Cast coil transformers are considered to be dry-type transformers.

a. Transformer turns-ratio and polarity tests. The turns-ratio test is used to determine the number of turns in one winding of a transformer in relation to the number of turns in the other windings of the same phase of the transformer. The polarity test determines the vectoral relationship of the various transformer windings. The tests are applicable to all power and distribution transformers. See figure 2-4 for a diagram of a typical fluid filled power transformers. Cast coil transformers are also subject to these tests. The turns-ratio test and the polarity test can be done on transformers of all sizes. The turns-ratio test is also commonly performed on instrument transformers. The test equipment used will ordinarily be a turns-ratio test set designed for the purpose, although, if not available, two voltmeters or two ammeters (for current transformers only) can be used. When two ac voltmeters are used, one is connected to the high-voltage winding and the other is connected to the low voltage winding. The high voltage winding is excited to a voltage not exceeding the rating of the voltmeter. Both voltmeters are read simultaneously. A second set of readings should be taken with the metering instruments interchanged. The values indicated should be averaged to calculate the ratio. A meaningful ratio measurement may be made using only a few volts of excitation. The transformer should be excited from the highest voltage winding in order to avoid possibly unsafe high voltages. Care should be taken during the application of voltage and during the measurement. It is important that simultaneous readings for both voltmeters be made. The voltmeters used should have accuracy's matching with the requirements of a 0.5 % ratio calculation. When a turns-ratio test is performed, the ratio should be determined for all no-load taps. If the transformer is equipped with a load-tap changer, the ratio should be determined for each load-tap changer position.

b. Fault-gas analysis. The analysis of the percentage of combustible gases present in the nitrogen cap of sealed, pressurized oil-filled transformers can provide information as to the likelihood of incipient faults in the transformer. Fault-gas analysis can be performed on mineral-oil-immersed transformers of all sizes. When arcing or excessive heating occurs below the top surface of the oil, some oil decomposes. Some of the products of the decomposition are combustible gases that rise to the top of the oil and mix with the nitrogen above the oil. The test set for this test is designed for the purpose. A small sample of nitrogen is removed from the transformer and analyzed.

c. Insulating-liquid analysis. Insulating-liquid analysis can be performed in the field on oil-immersed power transformers of all sizes. Regular tests, on a semiannual basis, should be made on insulating oils and askarels. Samples should be taken from the equipment and tested in accordance with the manufacturer's instructions.

2-7. Rotating machine testing

The tests described below are for rotating machines such as motors and generators. These tests are applied based on the horsepower and kVA rating of the machine.

a. Insulation-resistance (megger) testing. The insulation resistance test as described in paragraph 2-4d is also applicable to rotating machines. This testing procedure applies to armature and rotating or stationary field windings. If the insulation resistance is below the established minimum, circuit components should be tested separately until the low insulation reading is located. Insulation-resistance history based on tests conducted on new motors or after rewinding, cleaning, or from recorded data made under uniform conditions form a very useful basis for interpretation of a machine winding condition. When comparing records of periodic tests any persistent downward trend is an indication of insulation trouble even though the values might be higher than the recommended minimum safe values.

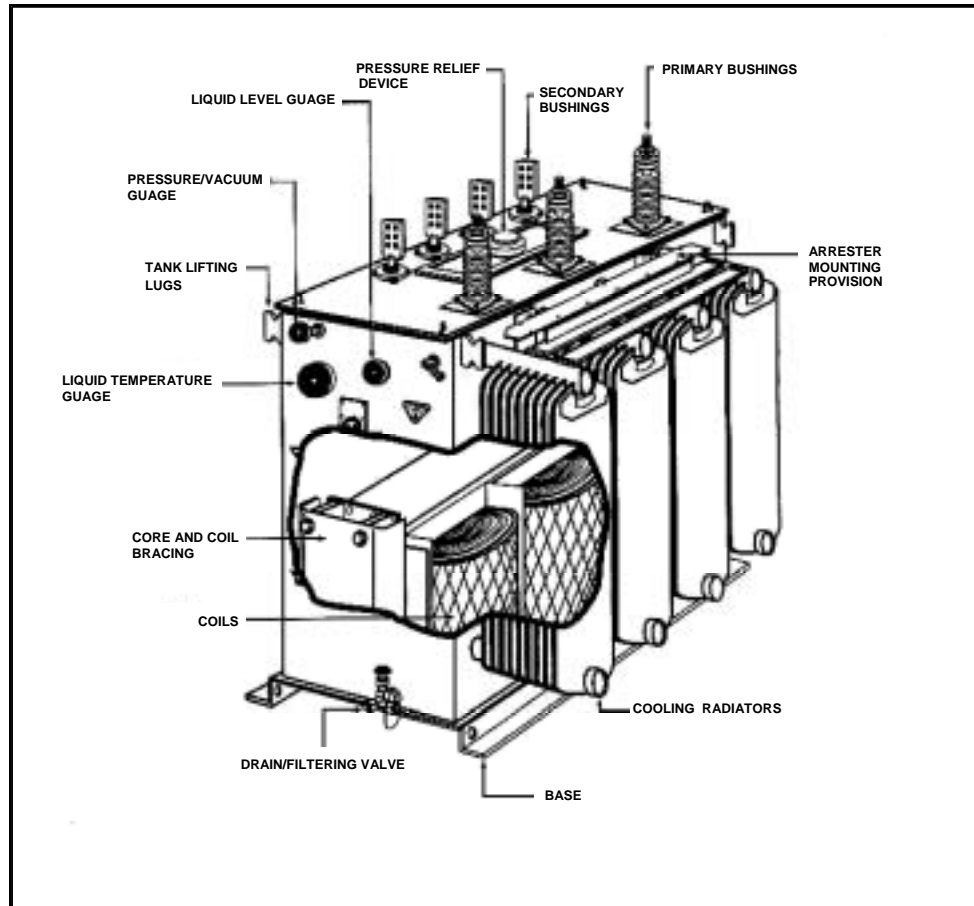


Figure 2-4. Power transformer diagram

(Reprinted from Department of the Army TM 5-686. Power Transformer Maintenance and Acceptance Testing 16 November 1998).

b. Dielectric-absorption testing. A dielectric absorption test for a rotating machine is performed as described in paragraph 2-4e. A more complete and preferred test than the insulation resistance test, the dielectric absorption test applies the voltage for 10 minutes or more to develop the dielectric-absorption characteristic. The curve obtained by plotting insulation resistance against time gives a good indication of moist or dirty windings. A steady rising curve is indicative of a clean, dry winding. A quickly flattening curve is the result of leakage current through or over the surface of the winding and is indicative of moist or dirty winding. If facilities are not available for a 10-minute test, a polarization index test can be performed by taking readings at 30 and 60 seconds. The ratio of the 60-to-30-second

or the 10-to-1-minute ratio will serve as an indication of the winding condition. Table 2-2 lists recommended acceptable values.

Table 2-2. Recommended minimum values of polarization index for all machine components insulation classes.

Thermal Class Rating	Minimum P.I.
Class 105	1.5
Class 130	2.0
Class 155	2.0
Class 180	2.0

The Polarization Index test is not applicable to noninsulated field windings (See IEEE Std. 43-2000 Section 12.2.1).

Note: The numbers in the thermal class rating are the hot-spot temperatures in degrees centigrade of the rotating machine. If the 1 min insulation resistance is above 5000 MΩ, the calculated P.I. may or may not be an indication of insulation condition and is therefore not recommended as an assessment tool.

From IEEE Std. 43-2000. Copyright © 2000 IEEE. All rights reserved.

c. Over-potential testing. Overvoltage tests are performed during normal maintenance operations or after servicing or repair of important machines or during commissioning. Such tests, made on all or parts of the circuit to group, ensure that the insulation level is sufficiently high for continued safe operation. Both ac and dc test equipment are available. The test overvoltages that should be applied will depend on the type of machine involved and level of reliability required from the machines. However, it should be of sufficient magnitude to search out weaknesses in the insulation that might cause failure. Standard ac over-potential test voltage when new is twice rated voltage plus 1000 volts ac. The dc over potential test is performed by applying a voltage and measuring the leakage current. The voltage applied during the acceptance test is a function of the equipment voltage rating as shown by the following equation:

dc acceptance test voltage in kV = $1.6[.8(2E + 1,000)]$ where E is the rated voltage in kV.

dc maintenance test voltage in kV = $1.6[.6(2E + 1,000)]$ where E is the rated voltage in kV.

These values for test voltages are given in *A Stitch in Time, Manual on Electrical Insulation Testing for the Practical Man*, Biddle Instruments, 1981. The standard duration of the test is between 1 to 5 minutes. The dc acceptance test voltage is applied to each winding separately with the other windings grounded. The voltage is applied in steps. First one third of the dc acceptance test voltage is applied. Leakage current readings are taken at one minute intervals up to a maximum of ten minutes. Then the voltage is increased in 1 kV intervals recording the leakage current and applied voltage at each step. Sufficient time shall be allowed between steps for the leakage current to stabilize. The data shall be plotted leakage current versus applied test voltage. The plot will yield a smooth curve with a rising slope for a good insulation system. Any sudden changes in the curve characteristics are an indication of impending failure. A high-potential test made to determine the condition of the insulation up to a predetermined voltage level is difficult to interpret. It is common practice to compare known good results against test specimens to determine what is acceptable and what fails the test.

2-8. Protective relays

Protective relays are used to sense abnormalities and cause the trouble to be isolated with minimum disturbance to the electrical system and the least damage to the equipment at fault. Protective relays should be set and acceptance tested prior to being placed in service and tested periodically thereafter to ensure reliable performance. In a normal industrial application, periodic testing should be done at least

every 2 years. The person performing the test should be given the settings to be applied to each particular relay by the engineer. There are two types of protective relays addressed in this manual. The first types are solid state relays. These are electronic "black box" devices. As all electronic devices, solid state relays should never be subject to hi-pot or megger testing. They typically come equipped with internal testing capabilities. Any diagnostic tests shall be performed as indicated in the manufacturer's manual. The second type is induction disk relays. They are subject to the following tests.

- a. *Inspection.* If recommended or desirable, each relay should be removed from its case (if relay design permits) for a thorough inspection and cleaning. If the circuit is in service, one relay at a time should be removed so as not to totally disable the protection. The areas of inspection are detailed in the manufacturer's instruction manual. These generally consist of inspection for loose screws, friction in moving parts, iron filings between the induction disk and permanent magnet, and any evidence of distress with the relay. The fine silver contacts should be cleaned only with a burnishing tool.
- b. *Settings.* Prescribed setting should be applied or it should be ascertained that they have been applied to the relay.
- c. *Pickup test.* In the case of a time-over-current relay, its contacts should eventually creep to a closed position with a magnitude of current introduced in its induction coil equal to the tap setting. The pickup is adjusted by means of the restraining spiral-spring adjusting ring. A pickup test on a voltage relay is made in much the same manner.
- d. *Timing test.* A timing test should be made on most types of relays. In the case of a time-over-current relay, one or more timing tests are made at anywhere from two to ten times the tap setting to verify the time-current characteristic of the relay. One timing point should be specified in the prescribed settings. Tests should be made with the relay in its panel and case, and the time test run at the calibration setting.
- e. *Instantaneous test.* Some protective relays are instantaneous in operation, or might have a separate instantaneous element. In this context, the term instantaneous means "having no intentional time delay." If used, the specified pickup on the instantaneous element should be set by test. Again referring to the relay used in the example above, at two times pickup, its instantaneous element should have an operating time of between 0.016 and 0.030 seconds.
- f. *Test of target and seal-in unit.* Most types of protective relays have a combination target and seal-in unit. The target indicates that the relay has operated. The seal-in unit is adjustable to pickup at either 0.2 or 2.0 amperes. The pickup setting is established by the relay coordination study. The setting for the seal-in unit should be specified with the relay settings. It should be verified by test that the contacts will seal in with the minimum specified direct current applied in the seal-in unit.
- g. *Test of tripping circuit.* A test should be made, preferably at time of testing the relays, to verify that operation of the relay contacts will cause the breaker to trip.

2-9. Ground system testing

In addition to the general component tests stated in the preceding paragraphs, there are tests to be performed on the system as a whole after the components are installed. They are as follows:

- a. *Equipment ground-impedance testing.* This test is used to determine the integrity of the grounding path from the point of test back to the source panel or supply transformer. A low-impedance grounding path is necessary to facilitate operation of the overcurrent device under ground-fault conditions as well as

provide a zero voltage reference for reliable operation of computers and other microprocessor-based electronic equipment. Instruments are available to measure the impedance of the grounding path. When using these instruments, the user should remember that, although a high-impedance value is an indication of a problem, for example a loose connection or excessive conductor length, a low-impedance readout does not necessarily indicate the adequacy of the grounding path. A grounding path that is found to have a low impedance by the use of relatively low test currents might not have sufficient capacity to handle large ground faults. Ground loop or grounding conductor impedance cannot be measured reliably in situations where metallic conduits are used or where metallic boxes or equipment are attached to metal building frames or interconnected structures. Such situations create parallel paths for test currents that make it impossible to measure the impedance of the grounding conductors; or even to detect an open or missing grounding conductor. Visual examinations and actual checking for tightness of connections are still necessary to determine the adequacy of the grounding path.

b. Grounded conductor (neutral) impedance testing. On solidly grounded low-voltage system (600 volts or less) supplying microprocessor-based electronic equipment with switching power supplies, this test is used to determine the quality of the grounded conductor (neutral) from the point of test back to the source panel or supply transformer. The same instruments used to perform the equipment ground-impedance tests can be used to perform grounded conductor (neutral) impedance tests.

c. Grounding-electrode resistance testing. Grounding-electrode resistance testing is used to determine the effectiveness and integrity of the grounding system. Periodic testing is necessary because changes in soil temperature, soil moisture, conductive salts in the soil, and corrosion of the ground connectors cause variations in soil resistivity. The test set used will ordinarily be a ground-resistance test set, designed for the purpose, using the principle of the fall of potential of ac-circulated current from a test spot to the ground connection under test.

d. Neutral-current testing. Situations exist where it is possible for the neutral current of three-phase systems to exceed the ampacity of the neutral conductor in normal operation. This is usually due to unbalanced phase loading, nonsinusoidal load currents (harmonics), or a combination of the two. Also nonlinear loads, such as rectifiers, computers, variable speed drives, electrical discharge lighting fixtures, and switching mode power supplies, cause phase currents that are not sinusoidal. The problem can be detected using a true root mean square (RMS) ammeter to measure the current flowing in the neutral conductor. The use of an average responding ammeter calibrated to read the RMS value of a sine wave should not be used as it will not yield valid results when used on nonsinusoidal waveforms. If the neutral current is found to be excessive, the current in each phase should be measured to determine if an abnormal condition exists. If excessive neutral current exists and the phase currents are not excessive, harmonic content is the most likely cause. A means of analyzing neutral current containing harmonic components is through the use of a wave or spectrum analyzer.